DETAILED LESSON OUTLINE

COURSE: Intermediate Wildland Fire Behavior, S-290

UNIT: 7—Fuels

TIME: 2 Hours

TRAINING AIDS: Overhead projector, slide projector, overhead pens, student workbook, roll of toilet paper, representative fuels from area for classroom demonstration

OBJECTIVES: Upon completion of this unit, students will be able to:

1 . List and describe seven characteristics of fuels that affect wildland fire behavior.

2. List and define by size class the four dead fuel timelag categories used to classify fuels.

3. Describe how fuel availability is essential to predicting wildland fire behavior.

4. Describe the fuel model concept and its utility for predicting wildland fire behavior.

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I. INTRODUCTION	
A. Present Unit Objectives	
B. Wildland Fuels	
Three of the seven factors in the fire environment that fireline personnel must monitor deal with wildland fuels: fuel characteristics, fuel moisture, and fuel temperature. This unit will help you to understand the relationship of fuels to the fire environment and recognize the variations in	

these fuels.

In fire behavior language, fuels are any organic material that is living or dead, in the ground, on the ground, or in the air that can ignite and burn. Fuels are found in almost infinite combinations of kind, amount, size, shape, position, and arrangement. The fuel on a given acre may vary from a few hundred pounds of sparse grass to 100 or more tons of logging slash. It may consist of dense conifer crowns, deep litter and duff, moss layers, and underground peat or a mixture of any of these forming a fuel complex.

We can estimate potential fire behavior by analyzing the physical properties and characteristics of fuels. Topographic and weather factors must also be considered before rate of spread and general behavior of fires can be determined.

UTILIZE SEVERAL SLIDES TO ILLUSTRATE THE DIFFERENT FUEL LEVELS.

C. Fuel Levels and Components

A systematic approach to looking at the fuel complex is to divide it into three broad levels—ground, surface, and aerial fuels. Through on-the-job experience, we can generalize the typical fire behavior under normal fire season conditions and evaluate properties of each fuel level that affect ignition and combustion. Let's take a closer look at these fuel levels.

1. Ground fuels

Although ground fuels are important in

relation to line construction and mop-up operations, because of their compactness, fire spread will be slowest, typically smoldering or creeping. Ground fuels have been known to hold fire through winter snows. What other examples of ground fuels can you list? Examples: deep duff, roots, and rotten buried logs.

2. Surface fuels

Surface fuels are less compact than ground fuels and have other characteristics more favorable for faster rates of spread. Surface fuels include litter, grass, and shrub to about six feet in height. If no aerial fuels are present, surface fuels have an open environment subject to stronger winds and more heating and drying by solar radiation. Thus, fires often run through this fuel level with higher rates of spread than if aerial fuels were present. Since most wildfires ignite in and are carried by the surface fuels, this fuel level receives the most emphasis.

3. Aerial Fuels

When aerial fuels are present we are concerned with crown or canopy closure. Timber stands with open canopies usually have a faster spreading surface fire than closed canopy stands, and torching of individual trees with possible spotting could occur. Unless very strong winds are present, crowning is unlikely without a closed canopy.

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Closed canopy stands that are greater than 6 feet in height whether timber or tall shrubs, offer the best opportunity for a running crown fire. Few fires become running crown fires; however, these fires are very important due to the large amount of fuel consumed in very short periods of time. Crown fire and the factors that contribute to its occurrence will be discussed further in Unit 11.

Canopy closure is usually given in percent (%). It is best demonstrated by looking at a forest from the air and seeing what percent of the ground is visible. If 25 percent of the ground is visible, there is 75 percent canopy closure.

II. LIST AND DESCRIBE SEVEN CHARACTERISTICS OF FUELS THAT AFFECT WILDLAND FIRE BEHAVIOR.

A. Principle Fuel Characteristics

Analysis of fuel complexes and their potential to support combustion and spread fire requires a more detailed study of individual fuel components. The seven principal characteristics of fuel components that can give us an indication of potential fire behavior within a fuels complex are: loading, size and shape, compactness, horizontal continuity, vertical arrangement, chemical content and moisture content. You should visualize these seven characteristics divided into two main categories: physical and chemical characteristics (that remain constant during a given fire situation), and moisture content (which changes continually). We will spend considerable time discussing these seven characteristics, and they should be well fixed in your mind by the end of this unit.

B. Fuel Loading

1. Definition

Fuel loading is the oven-dry weight of fuels in a given area, usually expressed in tons/acre or pounds/acre.

2. Fuel loadings vary greatly by fuel groups. Here are some examples of fuel loadings:

a. Grass - <1 to 5 tons/acre

b. Shrub - 2 to 80 tons/acre

c. Timber litter - 4 to 12 tons/acre

d. Logging slash - 10 to 200 tons/acre

When interpreting and predicting fire behavior, we are more concerned with the surface fuel loading; in particular those dead fuels that are less than 3 inches in diameter and live fuels of less than 1/4 inch diameter.

The total fuel loading on a site can be much more than what is shown here. Much of the vegetation on a site may not be available to carry fire due to its height above the ground or to high moisture levels. We will discuss the topic of fuel availability later in Objective #3.

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3. Fuel loading by class size

Fuel loadings are generally separated by different sizes of live and dead fuel particles. For analysis purposes the dead fuels are broken into four size classes according to their diameter. They are:

a. Grasses/litter - 0 to 1/4 inch in diameter

b. Twigs and small stems -1/4 inch to 1 inch in diameter

c. Branches - 1 inch to 3 inches in diameter

d. Large stems, branches - more than 3 inches in diameter

As we continue our study of fuels and fuel moistures, these size classes will gain more significance.

THIS IS COMMONLY A HARD CONCEPT FOR THE STUDENTS TO UNDERSTAND. INSTRUCTOR IS ADVISED TO BRING INTO CLASS SOME ACTUAL LOCAL FUEL EXAMPLES THAT ILLUSTRATE SURFACE-AREA-TO-VOLUME. A ROLL OF TOILET PAPER CAN BE USED TO ILLUSTRATE THIS CONCEPT.

C. Size and Shape

1. Surface-area-to-volume ratio

Surface-area-to-volume ratio is the ratio of the surface area of a fuel to its volume, using the same linear unit for measuring volume; the higher the ratio, the finer the particle.

Looking at surface-area-to-volume ratio is a method of characterizing the size and shape of fuels. Small fuels and flat fuels, like grasses, have a greater surface-area-to-volume ratio than larger fuels, like logs. The cube or block of fuel in Figure 6 of the workbook is 1 foot on each side and its volume is 1-cubic foot. The surface area of this cube is 6-square feet. If that same cube is divided up into 16 pieces as shown on the right, we have the same volume of fuel but now there is much more surface area to the 16 pieces. Calculations will show 18-square feet for the same cubic foot of fuel. This is three times the surface area of the cube on the left.

Why is this important to fire behavior? We know from our experiences in starting campfires, wood stoves, or fireplaces that small fuels ignite and sustain combustion easier than large pieces of fuel. Less heat is required to remove fuel moisture and raise a small fuel particle to ignition temperature.

The use of size classes will also give us a way to categorize the surface-area-to-volume ratios of fuels, but for now it is sufficient to remember that the smaller fuels have greater surface-area-to-volume ratios and, consequently will give up their moisture and raise their temperatures to the point of ignition quicker than larger diameter fuels.

2. Firebrands

The size and shape of the firebrands affect the amount and distance of spotting. Small embers ordinarily produce short-range spotting only, since they cannot sustain combustion for the period of time required in long-range transport. Cones, cedar fronds, bark plates and pine needles are examples of some firebrands that have been lifted into convection columns and then deposited 10 miles or more downwind from the fire.

In these cases, their flatness and greater surface-area-to-volume ratios have increased the aerodynamic qualities of the particles, thus making it easier for convection columns to lift them to greater altitudes.

The shape of fuels is also important to spotting downslope by rolling firebrands. Pine cones, round logs, and round yucca plants are particularly troublesome in their respective areas.

D. Compactness

1. Definition

Compactness can be simply defined as the spacing between fuel particles. The closeness and physical arrangement of the fuel particles effects both ignition and combustion.

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Fuels that are too closely compacted have less surface area exposed, restrict oxygen, and inhibit convective and radiant heat transfer. In most cases, we can expect a slower rate of spread when fuels are compacted.

Loosely compacted fuels will normally react faster to moisture changes and have more oxygen available for combustion. We can expect to have a fire with a greater rate of spread when fuels are loosely compacted.

MAKE SURE THE STUDENTS UNDERSTAND THE CONCEPT OF VERTICAL AND HORIZONTAL ORIENTATION BEFORE LEAVING THIS NEXT SECTION.

2. Fuel bed depth and orientation

Fuel bed depth is the average height of surface fuel that is contained in the combustion zone of a spreading fire front.

Orientation of the fuel refers to the horizontal or vertical orientation of the fuel array that carries the fire.

Fuel bed depth and orientation are significant fuel properties for predicting whether a fire will be ignited, its rate of spread, and its intensity. Grasses and shrubs are vertically oriented fuel groups, which rapidly increase in depth with an increase in fuel load. The timber litter and logging slash groups are horizontally oriented and slowly increase in depth as the load is increased. Observations of the location and orientation of fuels in the field help one decide which fuel groups are represented.

E. Horizontal Continuity

1. Definition

Horizontal continuity is the horizontal distribution of fuels at various levels or planes. This characteristic influences where a fire will spread, how fast it will spread, and whether the fire travels through surface fuels, aerial fuels or both.

2. Continuous vs. patchy fuels

If the open areas in this slide and in the workbook Figure 10 are barren and void of any fuels, it will obviously be difficult for fire to travel from one fuel island to another. It would probably require a strong wind with spotting for fire to travel through such discontinuous or patchy fuels. Such fire situations do occur, and what might appear to be natural firebreaks or barriers may not stop a fire's spread.

Continuous fuels, however, provide available fuels at one or more levels giving a fire opportunity to spread for great distances.

Horizontal continuity applies to all levels of the fuels complex, but the continuity of fine fuels is especially important to the spread of surface fires since wildland fires burn most often in this fuel level.

3. Horizontal continuity in aerial fuels

Before leaving horizontal continuity, we should consider continuity in the aerial fuels and the effects of a closed, versus open, timber canopy. A forest canopy not only shades surface fuels and prolongs moisture retention but also greatly reduces windspeeds from levels above the canopy to levels near the surface. Generally, the greater the crown closure, the greater the windspeed reduction. This certainly does have an effect on surface fires burning in these closed environments. If torching out of individual trees occurs, however, we have an entirely new fire environment with which to be concerned.

F. Vertical Arrangement

1. Definition

A very important fuels characteristic involved here is the vertical arrangement of fuels. We define vertical arrangement as the relative heights of fuels above the ground as well as their vertical continuity, both of which influence fire reaching various fuel levels or strata.

2. Fuel ladder

Why must you worry if you see fuel ladders on your fire? In some mature

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timber situations, we need to be concerned with several levels of fuels that may help transport fire from the surface fuel to the crowns. A subcanopy might consist of understory trees and larger regeneration. The canopy is made up of mature tree crowns perhaps over 100-feet tall. Fire may burn through one or more levels without burning the canopy. Regardless of the maximum height of the fuels and the number of fuel levels involved, we are concerned with the vertical continuity. When fuels are mostly vertically continuous, we call this a fuel ladder, or a ladder to transport fire into the canopy. The intensity of the surface fire and the live fuel moisture content usually determine whether fire will travel up through the green ladder fuels.

3. Reburn

A dangerous condition exists when a fire has only burned through the surface fuel level, drying the aerial fuels. A slight change in the environment, and the fire can cause a reburn of the canopy—a very dangerous situation.

The hazard during this condition can not be over emphasized. Firefighters must consider the reburn potential before entering an area that has only partially consumed fuels.

STRESS THE IMPORTANCE OF THIS POSSIBILITY.

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G. Moisture Content	

1. Fuel moisture content

   Fuel moisture content can be defined as the amount of water in fuel expressed as a percent of the oven-dry weight of that fuel. Fuel moisture content can vary in different fuel levels and thus influence whether these levels become involved with fire. Unit 8 will deal with fuel moisture in greater depth.

2. Dead and live fuel moisture contents

   In nature, fine dead fuel moisture very seldom gets below 3 or 4 percent. Fine dead fuel moisture fluctuates considerably over time due to several environmental factors. Live fuel moistures run much higher, perhaps 300 percent or more, but they change less rapidly than dead fuels. Can live fuels be consumed in a fire? Live fuels are frequently consumed by fire when there are enough dead, dry fuels present to support the fire, which can dry and ignite the live fuels.

   Fuel moisture, living or dead, plays a significant role in determining how quickly the fire will spread. Unit 8 will cover this in much more detail.

3. Fine dead fuels

   Fine dead fuels less than 1/4 inch, such as grass and needle/leaf litter, are most responsible for the spread of fire. In fact, the fine fuels are considered the primary carrier of a surface fire. We will be working with the moisture content of these fuels throughout our study of fire behavior.

4. Live-to-dead ratio

The live-to-dead ratio becomes critically important when evaluating the potential for a fuel to burn. The greater amount of dead fuel compared to live fuel, the more flammable the fuel is. Increased live-to-dead ratios are associated with over mature fuel complexes, damaged from fire, drought, disease, insects, wind, snow, or seasonal stress. The dead component of the fuel is extremely important since it is the dead material that carries the fire and heats the live component to ignition. With insufficient dead fuels present, a live stand may not burn even under good burning conditions. With a large dead fuel load, a live stand may burn very well even under modest conditions.

H. Chemical Contents

1. Definition

All fuels, living or dead, contain fiber that is known as cellulose. Fuels also contain chemicals and minerals that can enhance or retard combustion. Chemical contents include the presence of volatile substances such as oils, resins, wax, and pitch. There are certain fuels having rather high amounts of these volatile

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substances that can contribute to rapid rates of spread, high fire intensities, and can prolong burnout time. On the other hand, certain fuels may be high in mineral content, which can reduce fire spread and intensity.	
A wildland firefighter is primarily concerned with the volatile substances that make the job more difficult.	
A few fuels such as duff and "cow pies" are excellent receptors of firebrands that hold over fire primarily due to their high mineral contents. The high mineral content in these fuels enhances smoldering at much lower ignition temperatures.	
2. Volatile fuels	
Some well known fuels in which volatile substances contribute greatly to fire intensity and fire spread are the following:	
a. Chaparral in the southwest	
b. Palmetto in the southeast	
c. Greasewood in the pacific northwest	
d. Fountaingrass in Hawaii	
e. Pitchy stumps from some conifers	
There is much more that can be said about the chemical contents of fuels;	

however, we recommend that you investigate and become acquainted with problem fuels in your locality.

I. Fuel Characteristics Relation to Fire Behavior

POINT OUT THE REVERSED ARROWS ON THE SLIDE, EMPHASIZE THAT FUEL MOISTURE AFFECTS ALL OF THE FIRE BEHAVIOR CHARACTERISTICS.

Each of these seven characteristics contributes to one or more fire behavior processes. Let's take a few minutes to study these relationships. First, we're concerned with whether ignition will result in a sustaining fire. There are five fuel characteristics that most effect ignition. These are compactness, loading, chemical content, size and shape, and moisture content.

We can see here that there are six primary fuel characteristics involved with the rate of spread. How hot or intense will the fire be? What are the possibilities of spotting, torching, or crowning? We can relate individual fuel characteristics to each of these. Which fuel characteristic affects all of the fire behavior characteristics?

Answer: Fuel Moisture Content

III. LIST AND DEFINE BY SIZE CLASS THE FOUR DEAD FUEL TIMELAG CATEGORIES USED TO CLASSIFY FUELS.

A. Timelag

Timelag is a measure of the rate at which a specified size of dead fuel gains or loses moisture. The moisture content in fine dead fuels can change very rapidly, depending on the relative humidity of the air and precipitation. Moisture content changes in larger fuels, but at a much slower rate. How much slower? How do we predict what fuel moisture changes will occur in various fuels over periods of time? Various sizes of fuels are placed into convenient timelag categories or classes.

B. Dead Fuel Timelag Categories are:

1. l-hour timelag fuels - fuels that are 0 to 1/4 inch diameter

2. 10-hour timelag fuels - fuels that are 1/4 inch to l inch diameter

3. 100-hour timelag fuels - fuels that are l inch to 3 inches diameter

4. 1000-hour timelag fuels - fuels that are 3 inches to 8 inches diameter

These fuel sizes should look familiar. They are the size classes we discussed earlier. In Unit 8, Fuel Moisture, we will study the timelag concept more and make estimates of fine (1-hour timelag) fuel moisture percents from tables. Which of these timelag fuels loses its moisture the fastest after a rain?

Answer: 1 Hour

IV. DESCRIBE HOW FUEL AVAILABILITY IS ESSENTIAL TO PREDICTING WILDLAND FIRE BEHAVIOR.

A. Available Fuels

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Available fuels are those that will ignite and support combustion at the flaming front under specific burning conditions. Do all the fuels burn during the passage of a fire? The answer is no. Ordinarily only a portion of them burn, depending on factors of fuels availability.

B. Consumption of Various Fuels by Fires

In a cured grass stand, we might get nearly 100 percent of the fuels consumed by fire. These indeed have a very high degree of availability. A stand of shrub is seldom completely burned, but perhaps 5 to 95 percent is consumed. In timber litter, standing trees are only partially burned, and overall fire consumption might be 5 to 25 percent. The stumps, logs, and larger limbs of logging slash rarely are totally burned; thus, consumption in logging slash might be 10 to 70 percent.

C. Reasons for Consumption

Why does the amount of consumption vary in these previous examples? One assumption might be that the larger the fuels, the less likely it is that they will be totally consumed by fire. But more important is the assumption that some specific characteristics of the fuels made them unavailable for combustion. Certainly size, arrangement, and moisture content, as well as the duration and intensity of the fire, play an important part in a fuel's availability to burn.

THE INSTRUCTOR SHOULD GET A DISCUSSION GOING WITH THE STUDENTS ON WHY FIRE SOMETIMES DOES NOT CONSUME ALL AVAILABLE FUELS. STRESS THAT NOT ONLY

DIFFERENT FUEL TYPES HAVE VARYING FUEL MOISTURE, BUT ALSO WITHIN THE SAME FUEL TYPE, FUEL MOISTURE CAN VARY BETWEEN PLANTS.

D. Fuel Moisture Effect on Availability

The moisture content of both the live and dead fuels is the primary factor determining fuel availability. In this slide, the fine fuel moisture content was 2 percent and as you can see, about 95 percent of the fuel has been consumed. With all other environmental factors the same, at a fine fuel moisture of 12 percent, how much of the fuel do you think will be consumed?

EXERCISE 1 IS IN THE STUDENT WORKBOOK.

EXERCISE 1: Available Fuel

Part I

You should have placed a 1 in front of uniform grass cover, cured. This fuel can have up to 100 percent availability. The second most available is the logging slash, l-year-old. There may still be needles on the branches or they may have recently fallen. The large amount of fine, dead fuels makes these situations very available for combustion.

The third most available would be the heavy shrub, scrub oak. Since it is still mid-summer, the live moisture content of the brush would reduce the chances of a complete burn. We would rate the mature timber pine, last. Only a small percent of the total fuels would burn, and these would probably be confined to the surface level. You may have rated them differently, according to the percents of fuels consumed in Figure 14, thus putting shrub ahead of slash. The point to be made here is that you must look at all the characteristics to determine how available fuels will be for combustion.

Part II

Needles and small litter on the ground and cured grasses, if present, are usually most available and are the components that usually sustain a surface fire in timber.

Part III

Distribute various fuels from the area and have students present a discussion dealing with fuel characteristics and expected fire behavior. If possible, have fuels that illustrate various stages of drying; e.g., cheatgrass in green, purple, and straw stages.

V. DESCRIBE THE FUEL MODEL CONCEPT AND ITS UTILITY FOR PREDICTING WILDLAND FIRE BEHAVIOR.

We have seen so far that fuels in the fire environment can vary greatly as to size and shape, continuity, compactness, arrangement, chemical content, fuel moisture content, and availability. What if I asked you, "What kind of fuels do you have in your area?" What would you tell me? You can imagine if you started to describe the seven fuel characteristics to me, it would take some time. A better method of describing the fuels in the fire environment that considered the different combinations of fuel characteristics would really be helpful. Such a method has been created through the use of a fuel model.

THE DEFINITION OF A FUEL MODEL IS IN THE WORKBOOK. HAVE THE STUDENTS READ ALONG. REFER TO FIGURE 14 OF WORKBOOK.

A. Definition of a Fuel Model

A fuel model is a set of numbers that describe the fuel in terms that the fire spread model can use. The fire spread model and the method of predicting fire spread is introduced and further explained in S-390, Introduction to Wildland Fire Behavior Calculations.

Some components that are described include the seven fuel characteristics that you have studied. Various combinations of these components make up the fuel models. Although fuel models were developed as input to the fire spread model, they do provide the wildland firefighter a common way of describing the fuels.

The fuel models presented in this unit are part of the Fire Behavior Prediction System (FBPS). In this course fuels are discussed in terms of broad fuel groups. In S-390 fuels are broken out further into 13 fuel models.

B. Major Fuel Groups

There are four major fuel groups. The fuel groups are used to describe fuel complexes to make fire behavior predictions. The four major fuel groups are:

1. Grass

2. Shrub

3. Timber Litter

4. Logging Slash

The Introduction to Wildland Fire Behavior

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Calculations, S-390 course covers the differences in the 13 FBPS fuel models. If you are interested in learning more about these fuel models, obtain a copy of Hal Anderson's publication, "Aids to Determining Fuel Models for Estimating Fire Behavior," 1982 (NFES 1574). Let's now look at some examples of the four major fuel groups.

C. Fuel Group Slides

DURING THIS NEXT SECTION, INSTRUCTOR SHOULD REVIEW THE FUEL CHARACTERISTICS AND ASSOCIATED FIRE BEHAVIOR DESCRIPTIONS IN EACH FUEL GROUP; INSTRUCTOR MAY CHOOSE TO ENHANCE SLIDES WITH LOCALIZED EXAMPLES OF EACH GROUP PRESENT.

OPTIONAL: INSTRUCTOR CAN HAVE STUDENTS REFER TO THE FIRE BEHAVIOR FUEL MODEL DESCIPTIONS IN THE FIRELINE HANDBOOK—APPENDIX B, PAGES B-16 THROUGH B-20.

FIRE BEHAVIOR ESTIMATES GIVEN BELOW ARE WITH AN 8 PERCENT FINE DEAD FUEL MOISTURE CONTENT, LIVE FUEL MOISTURE WHEN PRESENT AT 100 PERCENT AND A 5 MI/H MIDFLAME WIND.

1. Grass group:

   Grass is the primary carrier of the fire. Fuel bed depth between 1 foot and 2.5 feet deep.

   Fuel characteristics:

   - fuel loading 300 pounds/acre to

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several tons/acre • size and shape generally less than 0.25 inches in diameter • compactness • moisture content responds quickly to changes in relative humidity Fire behavior characteristics: • rapid burnout • low intensity • wind strongly affects fire • ROS 35 to 100+ chains/hour • FL 4 to 12 feet 2. Shrub group: Shrub is the primary carrier of the fire. Fuel bed depth may range between 2 feet to 6 feet. Fuel characteristics: • fuel loading between 1 to 80+ tons/acre • size and shape of mixed dead and live fuels with small leaves, most fuels are less than 1 inch in diameter • compactness loosely layered to	

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very deep • moisture content of live fuels may be present • live fuel changes according to the amount of precipitation received and the time of year • chemical content in some fuels in this group will permit burning at higher fuel moistures Fire behavior characteristics: • very low to extreme rates of spread are possible • ROS 18 to 75 chains/hours • FL 4 to 19 feet 3. Timber litter group: Surface litter is the primary carrier. Fuel depth 0.2 to 1 foot Fuel characteristics: • size and shape mixed litter, leaves, needles to large branchwood • compactness ranges from loose to tight • vertical arrangement fuel bed depth less than 1 foot, typically less than 3 inches	

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- moisture content retained when litter compacted

Fire behavior characteristics:

- range from slow burning to running surface fires

- occasional torchouts to running crown fire possible

- ROS 2 to 8 chains/hours

- FL 1 to 5 feet

4. Logging slash group:

Logging slash is the primary carrier. Fuel depth 1 to 3 feet

Fuel characteristics:

- size and shape all sizes

- fuel loading between 12 and 58 tons/acre

Fire behavior characteristics:

- moderate to rapid spread rates

- moderate to high intensities dependent on fuel arrangement

- firebrands may be generated and convectively lifted

- rolling material frequently ignites fuel below

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- ROS 6 to 14 chains/hours
- FL 4 to 11 feet

VI. SUMMARY

An understanding of fuels and their characteristics is vital when learning about fire behavior. In the next unit you will see the importance of fuel moisture content and its relation to fire behavior.

VII. REVIEW UNIT OBJECTIVES

QUESTIONS.

HAVE STUDENTS COMPLETE UNIT 7 PROFICIENCY CHECK. ALLOW TIME IN CLASS OR HAVE THEM COMPLETE IT DURING THE EVENING AND PRESENT THE ANSWERS THE FOLLOWING DAY. THE ANSWERS TO UNIT 7 PROFICIENCY CHECK ARE IN APPENDIX D—EVALUATIONS, PAGE D-23 to D-25.

References:

Anderson, Hal E., 1982. Aids to Determining Fuel Models For Estimating Fire Behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22p.

DETAILED LESSON OUTLINE

COURSE: Intermediate Wildland Fire Behavior, S-290

UNIT: 8—Fuel Moisture

TIME: 3 Hours

TRAINING AIDS: Overhead projector, slide projector, overhead pens, student workbook, Fireline Handbook—Appendix B (optional).

OBJECTIVES: Upon completion of this unit, students will be able to:

1. Define critical live fuel moisture and the thresholds for various fuel types.

2. Identify three methods for obtaining live fuel moistures.

3. Describe the relationships among relative humidity, wind, and moisture content of fine and large fuels.

4. Explain how the amount and duration of precipitation and soil moisture affect moisture content of fine and large fuels.

5. Define the fuel moisture timelag concept and its value to firefighters and fire managers.

6. Describe how fuel moisture is determined for dead fuels in each of the four timelag categories.

7. Define moisture of extinction, how it varies in natural fuel complexes, and how it affects wildland fire ignition and spread.

8. Determine fuel moisture content for fine dead 1-hour timelag fuels from fuel moisture tables during daylight conditions.

9. Explain the differences between National Fire Danger Rating System (NFDRS) and Fire Behavior Prediction System (FBPS). (Could fit into Assessing Current & Predicted Fire Behavior.)

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I. INTRODUCTION	

A. Present Unit Objectives

B. Fuel Moisture

The fuel moisture content in natural fuels is such an important factor to fuels availability for fire ignition and combustion that we have devoted an entire unit to the subject. Most fuel complexes contain a combination of dead and live fuels; thus, a wide range of moisture contents occurs within these fuels. Since all fuels may not be involved in a flaming front or be consumed by fire, our analysis of fuel complexes must determine which fuels will be responsible for the propagation of fire.

The purpose of this unit is to help you make estimations of moisture content in various dead and live fuels and to identify those fuels which can burn. In Unit 10—Combining Influences Affect Basic Fire Behavior, you will observe how important fuel moisture content is in making fire behavior predictions.

1. Natural fuels and their moisture contents

Fuel complexes vary greatly by areas or regions with extremes ranging from sparsely vegetated deserts, to rain forests with lush vegetation, to parched timber lands. If we view each as a potential fire environment, our immediate assessments must include fuel assessments and fuel moisture contents.

We would expect desert fuels to be dry for extended periods, but is there enough fuel to carry fire? The rain forest has abundant fuels that are generally too wet or too green to burn, but infrequently these areas do have fires. Extended summer drought periods occasionally make our timber lands extremely dry, sometimes to the point of being "explosive," should fires occur.

We can generalize at this point and say that when fuel moisture content is high, fires ignite and burn poorly, if at all; and when it is low, fires start easily, and spread and burn rapidly. Fuel moisture contents are frequently some place between the two extremes and fluctuate with changes in weather and seasons. During normal fire seasons, firefighters and fire managers have experienced times when rapidly spreading fires suddenly stop, perhaps even go out, due to changes in fuels and moisture contents. These fuels may have been on a different aspect, had a later curing date, or experienced a sudden change in relative humidity.

2. Definition

Fuel moisture content is the amount of

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water in a fuel, expressed as a percent of the oven dry weight of that fuel. If there were no moisture at all in the fuels, as if dried in an oven, the fuel moisture content would be zero percent. Fuels can be weighed before and after drying in an oven, and percent can be determined by dividing the difference between the wet and dry weights by the dry weight. There are other, more practical ways of estimating fuel moisture percents in the field, and these will be discussed in this unit.	
YOU MAY REFER INTERESTED STUDENTS TO THE FOLLOWING PUBLICATIONS: "MEASURING MOISTURE CONTENT IN LIVING CHAPARRAL: A FIELD USERS MANUAL", GTR-PSW-36, COUNTRYMAN, CLIVE M., DEAN, 1979, AND "MEASURING FUEL MOISTURE CONTENT IN ALASKA; STANDARD METHODS AND PROCEDURES", GTR-PNW-171, NORUM, RODNEY A.; MILLER, MELANIE. 1984.	
II. NAME THE FIVE STAGES OF VEGETATIVE DEVELOPMENT OF LIVE FUELS, AND GIVE THE AVERAGE PERCENT MOISTURE CONTENT OF EACH.	
In estimating fuel moisture contents, you must remember that part of the fuel may be living vegetation, and part cured or dead vegetation. The two have different water retention mechanisms and different responses to the weather. Live vegetation has much higher moisture contents that fluctuate on a seasonal rather than a daily basis.	
A. Living Fuels	

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Living fuel includes both herbaceous plants and woody plant material. Herbaceous plants are either perennial, which sprout from the base, or annuals, which develop from seed each year. Herbaceous plants are relatively soft or succulent and do not develop woody, persistent tissue. The woody plant material that we are concerned with is small enough to be consumed in the flaming front of a fire.

Mostly, this includes leaves, needles, and twigs. Herbaceous plants die each year, thus producing more dead, fine fuels. In grasses, perennials usually cure out later than the annuals; this is an important factor in assessing fire potential.

1. Seasonal Variation

   In living woody vegetation, the high fuel moistures are primarily in the foliage, and in new shoots or stems. In these fuels, the moisture content normally decreases as the growing season progresses, with lowest amounts occurring by late summer or autumn.

   In subarctic continental environments, this can be reversed as the increased solar radiation frees more water from the frozen ground as the summer progresses.

   Deciduous plants produce dead, fine fuels; whereas, most evergreen plants that retain their needles or leaves more than one season may have substantially reduced moisture contents. Coniferous woody vegetation also produces dead fine fuels through needle casts.

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Here is an example of moisture content in live conifer foliage by season. The lines show old foliage or needles gaining some moisture in spring and early summer, then decreasing slightly into the fall season. New growth or new foliage initially has a very high moisture content in early summer but it decreases rapidly as the summer progresses.

2. Approximate live and fine dead fuel moisture ranges in natural fuels are:

   a. Living fuels--about 30 percent to over 300 percent.

   b. Dead fuels--about 2 percent to 30 percent.

   Why the big difference?

   Living cells have the capability of holding large amounts of water, while dead cells have been found to be fiber saturated at approximately 30 percent and can't absorb much more water.

B. Five Stages of Vegetative Development

Even though live fuel moisture content can be precisely determined by oven drying and weighing procedures, fire considerations are usually satisfied with a good estimate. Figure 4, page 198, is a table that gives approximate moisture content percents for five stages of vegetative development. These stages and their average moisture contents are a contributing factor to determining fire potential. These items

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can bring about abnormal fire seasons or burning conditions by decreasing moisture contents in live fuels and/or producing additional dead fuels within a fuels complex. 1. Long drought periods 2. Natural disease, insects 3. Annuals curing out early in the season 4. Harvesting of timber and other vegetation 5. Blowdown, ice storms C. Perennial and Annual Herbaceous Vegetation. Perennial and annual herbaceous vegetation, such as grasses, are a primary contributor to fire problems in many areas of the country. The amount of vegetation and the time of curing usually varies from year to year. Some perennial grasses never cure. In the grass fuel group the ratio of live-to-dead grass greatly influences fire spread. Normally at least 1/3 of the grasses must be dead before the fuel will carry fire. Grass color can be used with caution as an indicator of vegetative development. 1. One such species is *Bromus tectorum,* commonly called cheatgrass or annual brome. Although most common on dry areas of the west, it can be found in almost every state and is present in most continents of the world. Cheatgrass is a primary contributor to, and usually	

dictates, the severity of fire seasons on range lands in the Great Basin area of the United States. Here cheatgrass stands normally cure out by early summer to produce abundant, fine, flashy fuels, which are frequently termed "explosive" when fuel moistures are very low.

In some fuel types, coloration of the plant is an excellent indicator of its stage of development and probable moisture content range. As cheatgrass goes into its curing stage, it turns from green to purple; then, finally, it develops a straw color as it cures and its moisture content declines and fluctuates with changing weather factors.

You should also note fuel moisture in the living stage—above 100 percent; the curing or transition stage—30 to 100 percent; and the dead stage—below 30 percent. Fire will not ordinarily carry through cheatgrass until it reaches the dead stage and moisture contents drop below 30 percent.

The moisture contents in the three stages for cheatgrass would appear to be somewhat lower than these indicated in the live fuel estimates. Actually there will be some variation by species, and this should be used only as a general guide.

III. DESCRIBE THE RELATIONSHIPS AMONG RELATIVE HUMIDITY, WIND, AND MOISTURE CONTENT OF FINE AND LARGE FUELS.

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We will now move from a discussion of live fuel moisture to fine dead fuel moisture. The first and most important factor is fuel moisture exchange with the atmosphere.

A. Fuel Moisture Exchange with the Atmosphere

Fuels are constantly exchanging moisture with the surrounding air. During periods of high humidity and precipitation there is a net gain in fuel moisture. However, when the air is dry, with low humidity, fuels are giving up more moisture to the air than they receive. Several factors influence the rate of moisture exchange between fuels and the air. They are:

1. Difference in water vapor pressure between fuels and air

2. Presence or absence of wind

3. Size of fuels

4. Compactness of fuels

5. Proximity of fuels to damp soil

B. Equilibrium Moisture Content

If the moisture content in the atmosphere remained constant for a period of time, the fuels and the air would eventually achieve equal vapor pressures. This we call equilibrium moisture content, which occurs when there is no net gain or loss of moisture between fuels and the surrounding air. This can occur in small, fine fuels, but never occurs in larger fuels, as the time required to reach equilibrium in larger fuels is much longer.

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C. Environmental Factors Influencing Fuel Moisture

We will be discussing each of these factors in this unit. Note that fuel moisture is directly influenced by temperature, relative humidity, and precipitation. Wind alters the exchange of moisture between the fuels and the air.

Other site factors of weather and topography influence atmospheric temperatures and relative humidity. Each of these site factors indirectly affects fuel moisture and must be considered in making estimations of fuel moisture content.

1. Shade versus unshaded effects on fuel temperatures

   During sunny daylight hours, temperatures at the earth's surface can reach 160 degrees F. That temperature decreases very rapidly a few feet above the surface where air is mixing. At five feet above the surface, the air temperature may be 85 degrees as observed in a weather instrument shelter. Relative humidity is much lower where temperatures reach 160; thus, in this example, fine dead fuel moisture at the surface will be considerably lower—3 percent in the open, unshaded area, as opposed to 8 percent in a shaded area.

2. Aspect

   This graph illustrates the effects of aspect by time of day. Let's follow the curves through the 24-hour period shown.

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South slopes obviously receive more heating during the daytime than north slopes; thus temperatures are higher, relative humidity is lower, and fuel moisture ordinarily is lower on the south slopes. During the summer, level ground receives about the same intense heating as south aspects. When darkness comes, temperature differences on various aspects diminish, and by early morning, temperature, relative humidity, and fine fuel moisture values have mostly stabilized.

Remember that at night, temperatures on south slopes and valley bottoms may be much different due to surface inversions and the effects of thermal belts.

You should also note that east aspects reach their lowest fuel moisture contents by early afternoon; whereas, southwest aspects have the lowest afternoon fuel moisture contents. Normally, south and southwest aspects have the lowest average fuel moisture contents.

3. Time of the year

Time of the year influences the amount of solar heating received, thus affecting ground surface and air temperatures. For example, during March, Boise, Idaho receives about 1,250 Btu's per average day per square foot of horizontal surface. July receives the highest amount of solar heating at almost 2500 Btu's per average day per square foot. The average day in July receives twice as much solar heat as an average day in March.

Now let's look at September. It receives about 1,700 Btus per square foot on an average day. You may have noted that although solar equinoxes (equal days and nights) occur during the months of March and September, September receives considerably more solar heating than March. Why is this? Well, the reason is that there are more cloudy days at Boise during March than September. Actually, when the sun is shining, March 21 should receive about the same amount of solar heating as September 21. The point that we want to make here is that time of year has considerable influence on fuel temperatures and fuel moisture contents.

Latitude, or distance north of the equator, also has some effect on the amount of solar heating received. Although heating values will vary by locality, the shape of the Boise curve is mostly representative of that of the contiguous states. The curve will be considerably different for Alaska and northern Canada.

D. Elevation

The accepted "normal" temperature lapse rate is about 3-1/2° Fahrenheit decrease per 1,000 foot of elevation rise. Note that as temperature decreases with elevation, the relative humidity increases. We have determined fuel moisture percents for the given temperatures and relative humidities as listed at the right. In this example, with an elevation rise of 5,000 feet, fine dead fuel moisture contents have increased from 4 percent to 8 percent. Together with later snow melt dates, later curing dates and higher green to dead fuel ratios at higher elevations, the overall fuel moisture differences can be very significant to fire ignition and spread rates.

E. Slope

The steepness of slopes is a factor in the amount of solar radiation received on various aspects, and this affects the fuel moisture content of fuels on various slopes. You should note that surfaces perpendicular to incoming radiation receive considerably more heating than slopes that are almost parallel to these heat rays. The angle at which solar radiation hits various surfaces changes throughout the day and with the time of year.

The steepness or percent slope on north aspects is particularly important, as there may be times of the year when such slopes receive no direct solar heating at all.

F. Wind

Next, we recognize wind as a factor influencing fuel moisture from the standpoint of helping fuels to reach equilibrium moisture content with the atmosphere at a faster rate. Here's how windspeeds up the drying or the evaporation process. During calm air conditions, the air next to the fuels tends to become saturated with water vapor, decreasing the evaporation rate of moisture from the fuel. Wind removes this saturated air, continually replacing it with drier air and thus speeding up the evaporation process.

But moderate or strong winds may affect surface temperatures of fuels in the open and thereby influence surface fuel moisture. During daytime heating, wind may replace the warm air layers immediately adjacent to fuel surfaces with cooler air. This, in turn, raises the relative humidity in that area and lowers the fuel-surface temperature. Fuel drying is thereby reduced. At night, turbulent mixing may prevent surface air temperatures from reaching the dew point, thus restricting the increase of surface fuel moisture.

Foehn winds are frequently referred to as drying winds because they are so often accompanied by rapid drying of fuels. In the case of the foehn, it is warm and extremely dry air that is responsible for desiccation. The important role of the wind here, is to keep that warm, dry air flowing at a rapid rate so that it does not become moist by contact with the surface either by day or night.

The reverse is true, of course, when moist winds blow over dry fuels. They bring in a continuous supply of moisture to maintain a pressure gradient favorable for fuel moisture increase. In all of these moisture exchange processes, it should be remembered that wind has quite varied and complex effects on fuel moisture.

IV. EXPLAIN HOW THE AMOUNT AND DURATION OF PRECIPITATION AND SOIL MOISTURE AFFECT MOISTURE CONTENT OF FINE AND LARGE FUELS.

Precipitation can raise fine dead fuel moisture more

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rapidly than any other factor. Both the amount and duration of the precipitation are considerations when predicting fuel moisture increases in various size fuels.	
A. Fine Dead Fuels	
Fine, dead fuels react very rapidly to precipitation and reach their saturation points quickly. Additional rainfall has little effect on the fuels. However, more rainfall can be responsible for wetting the soils in contact with fuels, thus keeping those fuels damper for a longer period and prolonging the effects of the rainfall.	
B. Large Dead Fuels	
Large, dead fuels react more slowly to precipitation since much of the rain may run off the fuel. Fuels continue to absorb moisture throughout the duration of precipitation; thus duration is more important than amount.	
C. Comparison of Precipitation Duration Effects	
The horizontal axis represents hours of continuous precipitation, while the vertical axis is fuel moisture content in percent. The dashed line representing l-hour timelag (fine) fuels starts at 5 percent, rises rapidly, and reaches 30 percent moisture content within the first hour. The broken diagonal line representing 10-hour timelag fuels starts at 8 percent and increases at a slower rate, but reaches 30 percent moisture content after 6 hours. The solid line, that represents 100-hour (large) fuels starts at 12 percent and only reaches 20 percent after 16 hours of continuous precipitation. The data	

used to prepare this chart represent average western fuel situations with standing and down, dead fuels.

Although heavy rains penetrate vegetative canopies better to reach understory fuels, the moisture absorption rate into fuels is mostly fixed. Consequently, excessive amounts of rainfall run off the fuels. It should also be noted that a wetting rain will penetrate fuels better than high relative humidity in the air. Having free water on the surface of fuels induces a higher absorption rate than high humidities in the air.

EXERCISE 1: Relative Humidity, Precipitation, and Fuel Moisture

Fuel moisture content changes with changes in humidity and precipitation. Rank order the three types of fuels as to highest fuel moisture content for the hours given below. Place a 3 for the highest, a 2 for the next highest, and a 1 for the lowest in each column. All are near the ground surface.

Situation**:** A wildland area has experienced hot, dry weather for several weeks. Fuel moisture percents for the afternoon of August 1, at a nearby fire danger rating station were recorded as follows: 1-hour timelag fuels 3 percent, 10-hour timelag fuels 5 percent, and 100-hour timelag fuels 20-percent. Relative humidity is ranging between 22 percent during the day and 62 percent at night. The morning of August 2, the area received a 0.2-inch rainfall within a 2-hour period beginning at 0800. At approximately 1000 the clouds passed on, and the remainder of the day was warm and dry.

EXERCISE 1 Answers:

August August August August

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1 2 2 2
1500 0630 1000 1700

Small log (3-inch diameter)	20%	**3**	**2**	**3**
Dead branch (1/2-inch diameter)	5%	**1**	**1**	**2**
Clump of cured grass	3%	**2**	**3**	**1**

Discussion Time.

V. DEFINE THE FUEL MOISTURE

TIMELAG CONCEPT AND ITS VALUE TO FIREFIGHTERS AND FIRE MANAGERS.

A. Definition.

Timelag is an indication of the rate a fuel gains or loses moisture due to changes in its environment.

Timelag is a common occurrence in nature. When body temperature is taken orally the thermometer must be left under the tongue for approximately 3 minutes so that the instrument can adjust to its new environment. Three minutes is the timelag for an oral thermometer. Fuels also require a time period to adjust.

The gain or loss of moisture does not occur at a constant rate. When conditions change, fuels respond quickly at first. The change in moisture content becomes slower as the fuel moisture gets closer to the equilibrium moisture content. In nature, fuel takes five timelag periods for 95 percent of the change to occur, but most of the change occurs in the first timelag period.

With a greater surface-area-to-volume ratio the timelag of fine fuels is short, and they reach their equilibrium moisture content quickly. Large fuels have a longer timelag. They will not reach an equilibrium moisture content since environmental conditions do not stay constant. However, it is still worthwhile to classify fuels according to their timelag.

B. Timelag and Fuel Size Relationship

1. Timelag is related to fuel size.

On the horizontal axis, we have the size of branchwood in inches of diameter. The vertical axis gives us timelag in days. Fuels of 1.4 inches in diameter have a timelag of 48 hours or 2 days. Fuels 2 inches in diameter have a timelag of 4 days and so on. This means that if the air was kept at a constant point drier than the fuels, it would take 4 days' time for 2 inch branchwood to lose 2/3 of the difference between its initial moisture content and the equilibrium moisture content. What is the appropriate timelag for 8 inch diameter branchwood?

Answer: about 40 days

2. Reaction times of two different size fuels

The timelag concept can be observed by comparing the reaction times to wetting and drying for two different size fuels. The fuels are 1/2-inch sticks and a 12-inch log. During a typical fire season with a week of dry weather, the fuel moisture in 1/2-inch dead fuels will be considerably less than the moisture content of a 12-inch log.

Why? This is because the timelag period is much shorter in the 1/2 inch sticks. If the fuels experience a day with precipitation, the moisture content of both will go up, but note the rates at which they absorb moisture. The 12-inch log is still gaining moisture after the rain has stopped, perhaps because of free water and wet soils resulting from the rainfall. The 1/2-inch sticks gain moisture rapidly, but also lose it rapidly when temperatures and relative humidity return to normal.

As discussed earlier, wildland fuels come in many shapes and sizes, and we will never see a fuel complex of homogeneous fuel. A pure grass stand comes closest to being a homogeneous fuel. The wide variety of fuel components and changes in the weather make it virtually impossible for an entire complex to be at equilibrium moisture content at the same time.

C. Dead Fuel Timelag Categories

For the purpose of predicting fire behavior, it is acceptable to use estimates for the moisture content of the fuel sizes that contribute most to fire spread. Recall from Unit 7, dead fuels are grouped into four size classes based on timelag:

1. l-hour timelag fuels; 0 to 1/4 inch

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diameter	

2. 10-hour timelag fuels; 1/4 inch to 1 inch diameter

3. 100-hour timelag fuels; 1 inch to 3 inches diameter

4. 1000-hour timelag fuels; 3 inches to 8 inches diameter.

Thousand hour fuels are used in the National Fire Danger Rating System, but not for making fire behavior predictions. They are an indicator of drought.

To give you an example of how the groupings were made, let's look at the 100-hour category. It includes fuels from 1- to 3-inches in diameter. The midrange fuel size is 2-inches. Remember in our discussion on timelag related to fuel size that the timelag for 2-inch diameter fuels is 4 days. Four days is approximately 100 hours.

D. Fine Dead Fuel Moisture

Although it's helpful to have current estimates of fuel moisture in each of the four categories, we are most concerned with the l-hour group, which includes all fine or small fuels up to 1/4-inch in diameter. This is the group that mostly determines whether a fire will start and continue to spread. This is also the group that is constantly changing with changes in relative humidity. It is possible to predict these changes, and thus fire behavior, for different periods of the day and night.

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With no major air mass changes, relative humidity typically rises during the night with lowering temperatures until it reaches the highest humidity just about sunrise. Relative humidity then usually starts to drop with rising temperatures until the lowest humidity is reached during mid-afternoon. The fine dead fuel moisture curve follows the relative humidity curve with a short timelag of about 1 hour.	
Surface litter, as well as other fine dead fuels lying directly on the ground, can exhibit a slower moisture exchange rate because of reduced air circulation in compact fuels and soil moisture exchange with the fuels. In the last portion of this unit, you will be able to estimate fine dead fuel moisture content for various times of day or night, given atmospheric conditions and other site factors.	
VI. DESCRIBE HOW FUEL MOISTURE IS DETERMINED FOR DEAD FUELS IN EACH OF THE FOUR TIMELAG CATEGORIES.	
We have covered natural fuel complexes and their ranges of fuel moistures, environmental factors affecting fuel moisture, and the fuels timelag concept. We're now ready to discuss methods of determining fine dead fuel moistures and lead you through the steps to making your own calculations.	
A. Methods for Determining Fuel Moisture Contents	
Here are some ways in which fuel moisture contents can be determined for each of the timelag categories.	

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1. 1-hour timelag fuels: fuel moisture charts; rough estimate of relative humidity divided by 5; National Fire Danger Rating System (NFDRS) values; drying oven & scales.	
2. 10-hour timelag fuels: fuel moisture sticks; calibrated moisture meters; NFDRS values; drying oven & scales.	
3. 100-hour timelag fuels: calibrated moisture meters; NFDRS values; drying oven & scales.	
4. 1000-hour timelag fuels: calibrated moisture meters; NFDRS values; drying oven & scales.	
Determining fuel moisture percents for 100-hour and 1,000-hour timelag fuels gives managers an indication of drought conditions and overall severity of a fire season. The 10-hour fuels are much more important in making fire behavior predictions than 100-hour fuels, but not nearly as important as 1-hour fuels. One-hour fuels are the primary carrier of the fire. We will therefore work primarily with 1-hour timelag fuels in this course.	
VII. DEFINE MOISTURE OF EXTINCTION, HOW IT VARIES IN NATURAL FUEL COMPLEXES, AND HOW IT AFFECTS WILDLAND FIRE IGNITION AND SPREAD.	
Fire spreads as a result of fuels ahead of the fire being preheated to their ignition point. Heat is required to drive moisture from fuels before they can support combustion. At some point, fuel moisture content can slow combustion and the preheating of new fuels;	

thus, ignition temperature in new fuels is not reached.

A. Definition

What is that point where fine dead fuel moisture discourages combustion and fire spread?

We call it the moisture of extinction, and it is defined as the fuel moisture content at which a fire will not spread, or spreads only sporadically. The moisture of extinction varies by fuel situation. The moisture of extinction is dependent on various fuels characteristics such as fuel loading, fuel size, arrangement, and chemical content. Moisture of extinction is lowest (around 12 percent) for light grasses such as cheatgrass, and tends to be higher (around 30 percent) for more compacted fuels such as needle litter. For southern rough fuels, moisture of extinction is around 40 percent.

USE LOCAL EXAMPLES IF KNOWN MOISTURES OF EXTINCTION HAVE BEEN TESTED.

Does this mean a going fire will stop spreading when the moisture of extinction is reached? Not necessarily. A fire that is already spreading on a wide front and producing significant intensities may not respond when moisture of extinction is reached as an initiating fire would. Thus, a burnout may not spread while the main fire continues in a run.

B. Moisture of Extinction for the Fire Behavior Fuel Groups

Moisture of extinction ranges for each fuel group are:

1. Grass 12 - 25%

2. Shrubs 20 - 40%

3. Timber Litter 25 - 30%

4. Logging Slash 15 - 25%

Fuels such as shrubs with high chemical contents can burn at much higher fuel moistures.

VIII. DETERMINE FUEL MOISTURE CONTENT FOR FINE DEAD 1-HOUR TIMELAG FUELS FROM FUEL MOISTURE TABLES DURING DAYLIGHT CONDITIONS.

A. Fine Dead Fuel Moisture Tables

Now you will be introduced to tables that can give you acceptable estimates of 1-hour timelag fine dead fuel moistures, during daylight hours, under a variety of conditions.

We want to discuss briefly how the tables are to be used. Turn to Figure 17 and follow the process. First of all, you will determine a reference fuel moisture (RFM) by entering dry bulb temperature, relative humidity, and your location into a table. This can be made from a weather observation site location (site location) 2000 feet elevation difference from the fire location (projection point location). Next, you will determine a fuel moisture correction (FMC) value from the tables by considering the month, cloud and/or canopy cover shading, time of day, site location elevation difference, aspect, and slope percent. The correction value

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is then added to the RFM to get the adjusted fine dead fuel moisture (FDFM).	
1. Reference Fuel Moisture Table (Table 1)	
The RFM Table (Table 1) and the three FMC Value Tables (Tables 2, 3 and 4) are used to determine fine dead fuel moisture. Let's look at Table 1. This table is for RFM during daytime hours. You must enter both dry bulb temperature and relative humidity from your site. Notice the ranges of temperatures on the left, and ranges of humidities across the top.	
Select the appropriate ranges in which your values are included. With the appropriate temperature range, move horizontally until you intersect with the column for the appropriate humidity ranges at the top. At this intersection you have a RFM content percent. This value is entered in line 6 of the Fine Dead Fuel Moisture Worksheet.	
The Fine Dead Fuel Moisture Worksheet makes it easy to record the necessary Input items to determine the Reference Fuel Moisture (Input 6) and the Fuel Moisture Correction (Input 13) to arrive at the Fine Dead Fuel Moisture (Output 1).	
2. Fine Dead Fuel Moisture Content Corrections For Day (Table 2)	
Now look at Table 2. It gives you correction values for the months of May,	

June, and July. Notice that there are two sections to the table. The top section is for unshaded surface fuels, while the bottom part is for shaded surface fuels.

After making the proper selections of aspect and slope on the left, and time of day from the top, you will find FMC value at the point of intersection. This value is entered in line 13 of the Fine Dead Fuel Moisture Worksheet.

Fine Dead Fuel Moisture Correction Tables 3 and 4 are used for the months of February, March, April/August, September, October, and November, December, January, respectively.

It is important to use the proper elevation column on Tables 2, 3, and 4. Column B is used for temperature and relative humidity readings taken within 1,000 feet of elevation above or below the predicted position on a slope. When your area of concern is 1,000 to 2,000 feet above, use the A corrections. When 1,000 to 2,000 feet below, use the L corrections.

Elevations greater than 2,000 feet above or below the predicted site will require a new temperature and relative humidity reading.

3. Fine Dead Fuel Moisture.

Fine Dead Fuel Moisture is the sum of RFM (Input 6) and FMC (Input 13) on the Fine Dead Fuel Moisture Worksheet.

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Fine Dead Fuel Moisture is recorded as Output 1 on the worksheet.	

FUEL MOISTURE IS ONE OF THE SEVEN WILDLAND ENVIRONMENTAL FACTORS WHICH MUST BE CONTINUOUSLY MONITORED FOR SAFETY REASONS. THIS WILL BE FURTHER DISCUSSED IN UNIT 12—WILDLAND FIRE ENVIRONMENT FACTORS AND INDICATORS.

EXERCISE 2: Calculating Fine Dead 1-Hour Fuel Moisture

Use the fine dead fuel moisture calculation tables and worksheet to complete the items below:

1. What is the reference fuel moisture (RFM) for the following daytime situations?

   a. Temperature 85 °F, relative humidity 22 percent

      RFM **3**

   b. Temperature 60 °F, relative humidity 62 percent

      RFM **8**

2. What are the fuel moisture correction (FMC) values for the following situations?

   a. August 20, at 1200, mid-slope location, east aspect, and cloudy sky (shaded fuels)

      FMC **4**

   b. May 10, at 1400, south aspect, 20 percent slope, clear with unshaded fuels.

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FMC **0**	

3. What is the fine dead (1-hour) fuel moisture (FDFM) content at the following fire locations? Record your solution on the fine dead fuel moisture worksheet (Figure 19). Read the next two situations carefully!

   a. It is November 19, at 1500. Fuels are exposed to the sun on a west aspect. Readings from a belt weather kit taken 1500 feet below the fire give a dry bulb temperature of 92 °F, and a relative humidity of 16 percent. The slope is 40 percent.

   RFM **2** + FMC **3** = FDFM **5** 08-

   b. It is October 12, at 1700. Fuels are shaded on a north aspect, but under clear skies. Readings from a belt weather kit taken 1400 feet above the fire give a dry bulb temperature of 75 °F, and a relative humidity of 28 percent. The slope is 20 percent.

   RFM **4** + FMC **4** = FDFM **8** 08-

INSERT CHART

B. Figure 20 is a worksheet with the fine dead fuel moistures determined for a location where the weather observation was taken (L), where the weather observation was taken 1500 feet below (B), and where the weather observation was taken 1500 feet above (A) that location. Note the difference in the fine dead fuel moisture. Does this seem correct?

Back in Unit 3—Temperature/Humidity Relationships, we mentioned that warm air can hold more water than cold air. We also told you that relative humidity decreases as temperature increases and relative humidity increases as temperature decreases. Right?

These relationships help tell us why the fine dead fuel moisture is lower at 1500 feet below the weather observation location. The air temperature is naturally warmer and the relative humidity lower, resulting in a dryer fuel condition. For the 1500 feet above situation, the opposite is true. Colder air holds less water causing the relative humidity to be higher and the fine dead fuel moisture to be higher as well.

INSERT CHART

C. Interpretations of Fire Behavior

Now that you know what relative humidity and fuel moisture means, and how to estimate fine dead fuel moisture, what do you do with it?

The Fire Severity Related to Fuel Moisture Chart describes some general fire behavior problems that might occur with various fuel moisture levels in 1-hour and 10-hour fuels. Let us review this now.

Remember, these are ranges and the fire behavior descriptions are general. However, a quick review on the fireline can cue you to possible hazards or changes in your wildland fire environment.

IX. REGIONAL ADDITIONS.

X. REVIEW UNIT OBJECTIVES

HAVE STUDENTS COMPLETE UNIT 8

OUTLINE	AIDS & CUES
PROFICIENCY CHECK. ALLOW TIME IN CLASS OR HAVE THEM COMPLETE IT DURING THE EVENING AND PRESENT THE ANSWERS THE FOLLOWING DAY. THE ANSWERS TO UNIT 8 PROFICIENCY CHECK ARE IN APPENDIX D—EVALUATIONS, PAGE D-27 to D-29.	